

Final Report of NASA Grant NAG 1-2145

Project Title: Airframe-Jet Engine Integration Noise

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1. Objective

It has been found experimentally that the noise radiated by a jet mounted under the wing of an aircraft exceeds that of the same jet in a stand-alone environment. The increase in noise is referred to as jet engine airframe integration noise. The objectives of the present investigation are,

- (1) To obtain a better understanding of the physical mechanisms responsible for jet engine airframe integration noise or installation noise.
- (2) To develop a prediction model for jet engine airframe integration noise.

It is known that jet mixing noise consists of two principal components. They are the noise from the large turbulence structures of the jet flow and the noise from the fine scale turbulence. In this investigation, only the effect of jet engine airframe interaction on the fine scale turbulence noise of a jet is studied. The fine scale turbulence noise is the dominant noise component in the sideline direction. Thus we limit our consideration primarily to the sideline.

2. The Research Program

There are only limited experimental data and studies on jet-engine airframe integration noise in the open literature. The published studies have yet to identify clearly the dominant noise generation mechanism. Theory to predict this noise component was nonexistent at the beginning of this project. In a recent Boeing study a number of possible interaction noise mechanisms were found to be not important. They included:

- (i) engine installation location.
- (ii) size of the bifurcation
- (iii) small changes in the nozzle pitch angle

In view of the Boeing results, the focus of the present study is on the increase in the fine scale turbulence intensity due to the impingement of the downwash of the wing-flap on the jet flow. The downwash causes a severe deformation of the jet. It distorts the shape of the jet from a circular shape at the nozzle exit to a teardrop configuration 10 to 15 diameters downstream. This severe distortion of the jet flow leads to an increase in the fine scale turbulence intensity and hence the radiated noise.

To develop a prediction code for installation noise, the following research tasks were carried out.

- (a) Development of a theory and computer code capable of predicting the fine scale turbulence noise from non-circular jets.
- (b) Development of an extension of the theory of (a) to include the effect of forward flight.
- (c) Development of a potential flow code capable of calculating the downwash from a wing-flap combination.
- (d) Development of a parabolized RANS method that can predict the flow as well as the turbulence intensity and scales of a jet subjected to the downwash flow of item (c).
- (e) Development of a prediction method/computer code to assess the jet engine-airframe integration noise due to jet flow distortion as provided by item (d) above.

3. Research Results

In this section, the research results of the five research tasks outlined in the previous section are reported.

(a) Development of a theory and computer code capable of predicting the fine scale turbulence noise from non-circular jets

The most accurate jet mixing noise prediction theory (fine scale turbulence noise) in the literature is the theory of Tam and Auriault (AIAA J., vol. 37, 145–153, 1999). This theory was developed originally for circular jets. During the first year of this project, we have successfully extended this theory to nonaxisymmetric jets. The results have since been published in the AIAA J. (vol. 40, 2002). In the published paper, extensive comparisons between predictions and experimental measurements were reported. Good agreements were found for both subsonic and supersonic jets from elliptic and rectangular nozzles. This included a rectangular jet with aspect ratio as large as 7.0.

(b) Development of a fine scale turbulence noise theory for jets in forward flight

During the last quarter of the first year and the first part of the second year of this project, our research effort was to extend the theory developed in task (a) to include forward flight effects. To accomplish this goal, the mean flow and turbulence computation code was extended to account for the presence of a uniform flow outside the jet. To calculate the radiation noise, the adjoint Green's function was needed. The adjoint Green's function computation was modified to include forward flight. The results of our research work have now been published (Tam and Pastouchenko, AIAA J., vol. 39, 2001). Good agreements were found between

predictions and experimental measurements for both subsonic and supersonic jets at simulated forward flight Mach number as high as 0.4.

(c) Development of a potential flow code capable of calculating the downwash from a wing-flap combination

A key element in our study of jet engine airframe interaction mechanism is the downwash generated by the wing-flap. This downwash is instrumental in bending and distorting the jet flow. An accurate prediction code is, therefore, important. For this purpose, we developed an Euler code. The Euler code uses the Cartesian boundary treatment technique of Kurbatskii and Tam (AIAA J., vol. 35, 133–140, 1997). This technique allows the input of a wing and flap with arbitrary geometry and angle of attack. The code employs the Dispersion-Relation-Preserving (DRP) scheme. The required solution is obtained by time marching to a time independent state. To speed up convergence, the canceling-the-residue technique of Tam and Dong is adopted. This significantly reduces the run time of the code. This code has been tested extensively. The computing time is fairly short.

(d) Development of a parabolized RANS code capable of calculating the flow and turbulence intensity and scales of a jet subjected to the downwash of a wing-flap combination

Most parabolized codes are designed to satisfy homogeneous boundary conditions. In the wing-flap downwash jet flow interaction problem, the flow has to merge smoothly to the given downwash. This means that the parabolized code must satisfy prescribed side boundary conditions. To meet this requirement, we completely reformulated the parabolization procedure. This new formulation allows the prescription of arbitrary downwash as boundary condition. To account for turbulence in the jet flow, the k - ϵ turbulence model with modified coefficients of Thies and Tam is used. To run the code, the first step is to execute the Euler code of Task C to determine the downwash flow field. The downwash flow field is then used as an input to the Parabolized RANS Code for calculating the jet flow and turbulence intensity as well as turbulence length and time scales. Extensive testings have shown that the code is robust and efficient. Numerical results reveal that for flap setting corresponding to landing configuration, the jet flow is highly distorted by the downwash. Slightly downstream of the flap trailing edge, the cross section of an initially circular jet has the shape of a tear drop. The mixing layer on the bottom side is thinner than that on the top. The turbulence intensity distribution is also highly non-axisymmetric.

(e) Jet engine airframe integration noise

To calculate jet engine airframe integration noise due to the distortion of the jet flow by the downwash of the wing-flap, we used the theory of Tam and Auriault. The turbulence intensity and length and time scales as computed by the parabolized RANS code of Task D provided the necessary input to the noise source model. The

mean flow refraction effect was accounted for through the computation of the adjoint Green's functions. A special computer code was developed to compute the adjoint Green's function. This code also included the reflection of sound waves by the bottom side of the wing as well as simulated forward flight. We believe that this noise prediction code contains the essential physics of jet engine airframe interaction.

Because only limited amounts of experimental data on jet engine airframe integration noise is available in the literature, extensive comparisons between theory and measurements are not possible. We identify the Boeing data as a good database for comparison. In the sideline direction, our code predicts a noise increase of about 3 dB in the high frequency range. This matches well with the Boeing measurement. The directivity of the noise increase is also in fair agreement. The Boeing data, however, shows a peak in the mid-frequency range that is not predicted by the computer code. The mid-frequency range noise increase is most likely due to the interaction of the large turbulence structures near field with the wing flap when the flap is fully deployed. Calculating this noise component is beyond the scope of the present investigation as we are restricted in time and effort to concentrate on noise related to the fine scale turbulence of the jet flow.

4. Future Effort

The theories and computer codes developed in this project have significantly improved the jet noise prediction capability beyond what was available at the beginning of the project. We are now able to compute the fine scale turbulence noise from non-axisymmetric jets with or without forward flight. We are now able to quantify the distortion of the mean flow of a jet by the downwash of a wing flap combination. We are also capable of calculating the high frequency part of the jet engine airframe integration noise. What remains to be done are all related to the noise from the large turbulence structures of the jet flow. We strongly believe that this should be one of the main focuses of any future effort.

5. Publications

The following publications were made possible by the support of this research grant.

Tam, C.K.W. and Pastouchenko, N.N., "Noise from fine-scale turbulence of non-axisymmetric jets", *AIAA Journal*, vol. 40, 456-464, 2002.

Tam, C.K.W. and Pastouchenko, N.N., "Effects of forward flight on jet mixing noise from fine scale turbulence", *AIAA Journal*, vol. 39, 1261-1269, 2001.

- Pastouchenko, N.N. and Tam, C.K.W., "Jet noise at take-off and landing", AIAA Paper 2002-2603, 2002.
- Tam, C.K.W. and Pastouchenko, N.N., "Gap tones", AIAA Journal, vol. 39, 1442-1448, 2001.
- Tam, C.K.W. and Kurbatskii, K.A., "A wavenumber based extrapolation and interpolation method for use in conjunction with high-order finite difference schemes", Journal of Computational Physics, vol. 157, 588-617, 2000.
- Tam, C.K.W. and Kurbatskii, K.A., "Multi-size-mesh multi-time-step dispersion-relation-preserving scheme for multi-scales aerocoustics problems", AIAA Paper 2002-0224; to appear in the International Journal of Computation Fluid Dynamics.
- Tam, C.K.W., "Computational aerocoustics examples showing the failure of the acoustic analogy theory to identify the correct noise sources", Journal of Computational Acoustics, vol. 10, 387-405, 2002.